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FINE-PARTICLE MEASUREMENT INSTRUMENT
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SPECIFICATION /349*

1. Title

Fine-Particle Measurement Instrument

2. Claims

A fine-particle measurement instrument that measures fine particles adhering to the surface of a substrate for semiconductor-device use and floating fine particles by utilizing scattering caused by laser beams, said instrument comprising:

a laser-beam phase modulation section that generates two laser beams whose wavelengths are the same and whose phase difference is modulated with a predetermined frequency,

an optical system that causes the aforesaid two laser beams to intersect each other in a space that contains the aforesaid measurement-target fine particles,

a photodetector that receives the light scattered by the measurement-target fine particles in the area in which the aforesaid two laser beams intersect and converts the light into electrical signals, and

a signal-processing section that extracts, from the electrical signals generated by the scattered light, signals whose frequencies are the same as or twice the frequency of the phase-modulation signal used by the aforesaid laser-beam phase modulation section and whose

* Number in the margin indicates pagination in the foreign text.

phase difference from the aforesaid phase-modulation signal is constant in terms of time.

3. Detailed Description of the Invention

[Industrial Field of Application]

The present invention pertains to a fine-particle measurement instrument for measuring fine particles (foreign matter) that are present in apparatuses used for such processes as film forming, etching, cleaning, etc., and it pertains to, for example, a foreign-matter inspection apparatus for wafers.

[Prior Art]

Figure 3 is a structural drawing that illustrates a fine-particle measurement instrument that is a first prior-art example presented in, for example, JP-B-S63-30570, and this instrument is for measuring fine particles adhering to the surface of a wafer. In the figure, reference numeral 1 is a semiconductor-device-use substrate (wafer) to be measured; 2, a fine particle; 3, a laser-beam source (a light source for generating parallel beams); 4, a polarizer; 5, a field lens; 6, a photodetector that converts light into electrical signals; 7, an electronic circuitry unit that processes the data output from the photodetector (6) and obtains a fine-particle measurement result; and 8, a driving mechanism for moving the position of the wafer.

The following explains the operation of the first prior-art example.

Laser beams emitted from the laser-beam source (3) are irradiated in parallel with the wafer surface. Here, S-polarized laser beams, /350 for example, are used. S-polarized laser beams are scattered by the fine particle (2), but, because the fine particle has minute asperities on its surface, the scattered light becomes a light that contains many P-polarized components. Meanwhile, the medium of the measured ambience is usually a gas comprised of air, and Rayleigh scattered light caused by gaseous molecules does not contain P-polarized components. Therefore, the light scattered by gaseous molecules is blocked by the polarizer (4) provided so as to block S-polarized components, and, among the scattered light from the fine particle, only the P-polarized components are received by the photodetector through the field lens (5), and the measurement result is obtained at the electronic circuitry unit (7). The driving mechanism (8) is provided for measuring the distribution of the fine particles on the wafer surface.

Figure 4 is a structural cross-sectional drawing that illustrates a fine-particle measurement instrument that is a second prior-art example presented in, for example, J. Electrochem. Soc., A. Shintani, et al., [124, No. 11 (1977) 1771]. In the figure, reference numeral 3 is a laser-beam source; 9, an observation space area that is spatially limited by the receiving lens system (10) and that contains fine particles to be measured; 6, a photodetector; and 11, an optical trap for suppressing stray light.

The instrument of this prior-art example is connected to a processing unit for use, utilizing a capillary (tube), and it draws the fine-particle-containing gas inside the processing unit so as to measure the fine particles inside the processing unit indirectly.

Figures 5 (a) and (b) are a plan view and frontal view, respectively, that illustrate the operation principle of an in-situ particle flux monitor, which is a third prior-art example.

By repeating the reflection of a laser beam from the laser source (3) many times between the mirrors (21) disposed in parallel, the two-dimensional observation space area is expanded. When fine particles travel through this space area, scattered light is generated, and the measurement of the fine particles is executed by receiving this scattered light with the photodetector (6). Reference numeral 22 is a reflector/collector, and 23 is a beam stopper. This instrument is placed inside a processing unit for use.

[Problems that the Invention Intends to Solve]

Since the fine-particle measurement instrument of the first prior-art example is configured as described in the foregoing, the surface of the fine particles must have minute asperities that cannot be considered to be too small in comparison to the wavelength of the laser beams; therefore, this instrument has difficulty in measuring smooth fine particles with few asperities and fine particles having rather small particle sizes. Although measurement can be carried out using P-polarized or non-polarized laser beams instead of S-polarized

laser beams, Rayleigh scattered light (P-polarized light) caused by the gas in the measured ambience cannot be blocked by the polarizer (4), and, as a result, the S/N ratio cannot be increased, and it is difficult to measure fine particles having rather small particle sizes. Furthermore, this prior-art instrument is not intended to be used for measuring fine particles inside processing units but to be used as an off-line inspection instrument, and, although the polarizer and field lens (which comprise a microscope) are positioned extremely close to a wafer so as to limit the observation space area, the application of this instrument to measurement in a processing unit is difficult to implement.

The fine-particle measurement instrument of the second prior-art example cannot measure fine particles on the surface of a wafer placed inside a processing unit, and, even with respect to the fine particles floating inside a processing unit, only those that are successfully drawn and successfully transported to the measuring instrument can be measured.

The fine-particle measurement instrument of the third prior-art example can measure floating fine particles but not those adhering to the surface of a wafer. Furthermore, a laser-beam source, mirrors, photodetectors, etc., are placed inside a processing unit; therefore, taking a process of forming film by normal-pressure heat CVD as an example, it is difficult to measure floating fine particles above a wafer heated to a high temperature or those near the area directly

above it during the film-forming process, and, even during a period in which a film is not formed, this instrument, when installed inside a processing unit, becomes a factor that greatly changes the environment, including the flow of a gas, temperature distribution, etc., near the wafer. In the etching and cleaning processes, this instrument also has difficulty in carrying out the measurement without causing a significant disturbance. Furthermore, the measurement method of this instrument is not designed to eliminate signals caused by Rayleigh 351
scattered light from a gas comprising the ambient medium, in other words, the background signals; therefore, it is difficult to take measurements when the scattered light caused by fine particles has such a weak scattered-light intensity that it is buried inside the background, that is to say, when fine particles have small particle sizes.

The present invention was achieved to solve the aforesaid problems, and it intends to obtain a fine-particle measurement instrument that can measure fine particles adhering to the surface of a wafer placed inside an apparatus used for film forming, etching, cleaning, etc., and fine particles that are floating in the space over the wafer with high spatial resolution, without causing a significant disturbance to the environment inside the processing unit or to the process proper.

[Means for Solving the Problems]

The fine-particle measurement instrument of the present invention is equipped with a laser-beam phase modulation section that generates two laser beams whose wavelengths are the same and whose phase difference is modulated with a predetermined frequency, an optical system that causes the aforesaid two laser beams to intersect each other in a space that contains the aforesaid measurement-target fine particles, a photodetector that receives the light scattered by the measurement-target fine particles in the area in which the aforesaid two laser beams intersect and converts the light into electrical signals, and a signal-processing section that extracts, from the electrical signals generated by the scattered light, signals whose frequencies are the same as or twice the frequency of the phase-modulation signal used by the aforesaid laser-beam phase modulation section and whose phase difference from the aforesaid phase-modulation signal is constant in terms of time.

[Operation]

Since the present invention has the aforesaid configuration, the influence of stray light other than the influence of the laser beams can be eliminated from the measured signals, and the measurement space area is limited to the area in which two laser beams intersect each other, thus making it possible to implement measurements with a high S/N ratio and high spatial resolution. Furthermore, within this limited measurement space area, the signal component caused by the

Rayleigh scattered light of the ambient medium can also be eliminated in the range in which the ambient medium in the area can be deemed homogeneous; thus, it becomes possible to implement measurements of fine particles with high spatial resolution, with the disturbance factors' being well suppressed in the measurements.

By moving the intersection of the two laser beams within the processing unit, two-dimensional distribution of particles on the wafer surface and three-dimensional distribution of particles in the space above the wafer can be obtained.

[Embodiments]

The following explains one embodiment of the present invention, referring to figures.

In Fig. 1, reference numeral 1 is a semiconductor-device-use substrate (wafer) placed inside a processing unit (12); 2, fine particles adhering to the surface of the wafer (1); 3, a laser-beam source; 23, a laser-beam phase modulation section that forms, between the P-polarized component and S-polarized component of the laser beam, a phase difference that is modulated by a predetermined frequency; 24, a polarized-beam splitter that splits a laser beam into two laser beams, the P-polarized component and S-polarized component; 4, a polarizer; 6, a photodetector that receives the laser light scattered by fine particles that are present in the area in which the two laser beams intersect each other, in other words, in the measurement space area, and that converts it into electrical signals; and 25, a signal-

processing section that extracts, from the electrical signals output by the photodetector (6), signals whose frequencies are the same as or twice the frequency of the phase-modulation signal used at the laser-beam phase modulation section (23) and whose phase difference from the phase-modulation signal is constant in terms of time, said signal-processing section being implemented by, for example, a lock-in amplifier. Reference numeral 26 is a photodetector that receives synthesized light of the two laser beams that have traveled through the inside of the processing unit (12) and have come out from it and that converts the light into electrical signals, and it is similar to photodetector **6**. Reference numeral 27 is a signal-processing section that extracts, from the electrical signals output by the photodetector (26), signals whose frequencies are the same as or twice the frequency of the phase-modulation signal used in the laser-beam phase modulation section (23) and whose phase difference is constant in terms of time, said signal-processing section being implemented by, for example, a lock-in amplifier and similar to signal-processing section **25**.

The measurement section that is mainly configured from the photodetector (26) section and signal-processing section (27) is for monitoring the operation of the measurement instrument of the present invention, and it does not constitute the essence of the measurement principle of the present invention. Reference numeral 28 is a data-processing section that obtains data regarding fine particles based on the signals sent from signal-processing section **25**, while taking the

signals from the signal-processing section **27** into consideration. /352

The following explains the operation. A laser beam emitted from the laser-beam source (3) is split into two laser beams whose phase difference is modulated with a predetermined frequency by the laser-beam phase modulation section (23) and the beam splitter (24) and subsequently irradiated upon the surface of the wafer (1) placed inside the processing unit (12) or made to travel through the space above the surface of the wafer (1). Here, when the two laser beams intersect each other on the surface of the wafer (1) or in the space above the surface, the interference fringe is formed in this intersection.

Figure 2 (a) is presented to explain this state, and, in the figure, reference numerals 29 and 30 indicate two laser beams; 31, the intersection; 32, the formed interference fringe; and 2, particles to be measured. Because the phase difference between laser beam **29** and laser beam **30** is modulated with a predetermined frequency, the position of the interference frequency (2) moves in sync with this modulation. Therefore, as shown in Fig. 2 (b), the distribution pertaining to the position of the intensity of the interference fringe moves periodically at the positions of the fine particles; as a result, the light scattered by the fine particles is synchronized with the modulation signal of the phase difference of the two laser beams. Therefore, referring back to Fig. 1, the fine particles can be measured by converting the scattered light from the fine particles

into electrical signals by the photodetector (6) and by extracting by the signal-processing section (25), from these signals, signals whose frequencies are the same as or twice the frequency of the phase-modulation signal used in the laser-beam phase modulation section (23) and whose phase difference is constant in terms of time. Meanwhile, even if there is, in the intersection of the two laser beams, Rayleigh scattered light that is caused by the ambient medium and that interferes with the measurement of the fine particles, it is possible, in the range in which the ambient medium can be considered to be homogeneous in the region in which the interference fringe moves, to eliminate the signals caused by the Rayleigh scattered light. Consequently, compared with the prior-art examples, the method of the present invention makes it possible to measure fine particles having smaller particle sizes with a dramatically higher S/N ratio and higher spatial resolution.

The foregoing explanation only referred to the measurement of fine particles located inside a processing unit, but the method employed for this measurement instrument can, of course, be applied to a measurement instrument that is separate from a processing unit and that is designed for a measurement purpose only, and this method is highly effective even when it is applied to a foreign-matter inspection apparatus for wafer surfaces.

In the foregoing, the measurement of fine particles in only one area of the wafer surface or of the space above the wafer surface is

explained. However, in Fig. 1, by adding a mechanism that can move the intersection of the two laser beams to a desired position within the processing unit (12), the two-dimensional distribution of the fine particles adhering to the wafer surface can be easily measured with respect to the wafer (1) surface, and the three-dimensional distribution of the floating fine particles can be easily measured with respect to the space above the wafer (1) surface.

Furthermore, in Fig. 1, in order to generate two laser beams whose wavelengths are the same and whose phase difference is modulated with a predetermined frequency, the phase difference between the P-polarized component and S-polarized component of a laser beam is modulated by the laser-beam phase modulation section (23), and the laser beam is subsequently split into two laser beams by the polarized-beam splitter (24). However, the laser beam may be split into two beams first, after which one of them may be phase-modulated, and this case can also yield the same effects as the embodiment presented before.

[Effects of the Invention]

As shown in the foregoing, according to the present invention, the measurement instrument has a laser-beam phase modulation section that generates two laser beams whose wavelengths are the same and whose phase difference is modulated with a predetermined frequency, an optical system that causes the aforesaid two laser beams to intersect each other in a space that contains the aforesaid measurement-target

fine particles, a photodetector that receives the light scattered by the measurement-target fine particles in the area in which the aforesaid two laser beams intersect and converts the light into electrical signals, and a signal-processing section that extracts, from the electrical signals generated by the scattered light, signals whose frequencies are the same as or twice the frequency of the phase-modulation signal used by the aforesaid laser-beam phase modulation section and whose phase difference from the aforesaid phase-modulation signal is constant in terms of time. As a consequence, the present invention has the effect of making it possible to measure fine particles on the surface of a semiconductor-device-use substrate placed inside a processing unit or fine particles floating in the space above the surface of the aforesaid substrate with a high S/N ratio and with high spatial resolution, without causing any significant disturbance to the environment of the processing unit or the process proper, and also the effect of making it possible to measure fine particles having rather small particle sizes.

4. Brief Explanation of the Drawings

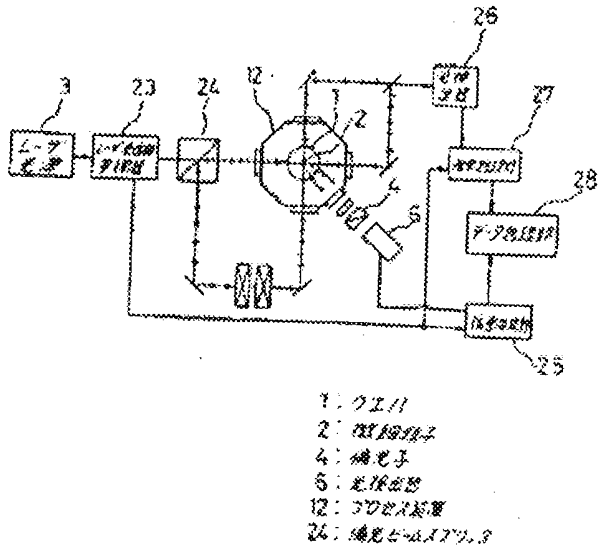
Figure 1 is a cross-sectional drawing that illustrates a fine- /353 particle-measurement instrument according to one embodiment of the present invention. Figure 2 (a) and (b) are schematic drawings for explaining the measurement principle of the present invention. Figure 3 is a structural diagram for illustrating the operational principle of a fine-particle-measurement instrument of the first prior-art

example. Figure 4 is a cross-sectional drawing for illustrating the operational principle of a fine-particle-measurement instrument of the second prior-art example. Figure 5 (a) and (b) are a plan view and frontal view for illustrating the operational principle of a fine-particle-measurement instrument of the third prior-art example.

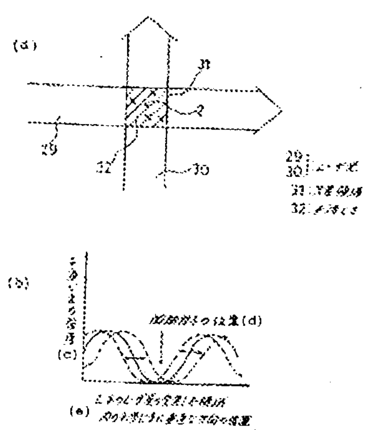
1 ... wafer, 2 ... fine particle, 3 ... laser-beam source, 4 ... polarizer, 5 ... field lens, 6 ... photodetector, 7 ... electronic circuitry unit, 8 ... wafer-driving mechanism, 9 ... observation space area that contains fine particles to be measured, 10 ... receiving lens system, 11 ... optical trap, 12 ... processing unit, 21 ... mirror, 22 ... reflector/collector, 23 ... beam stopper, 24 ... polarized beam splitter, 25 ... signal-processing section, 26 ... photodetector, 27 ... signal-processing section, 28 ... data-processing section.

In the figures, the same reference numerals indicate the same or equivalent components.

[FIG. 1]

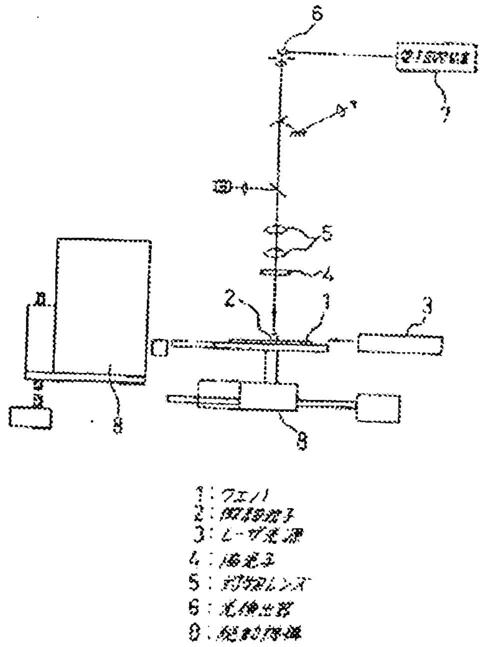


[FIG. 2]



Key: c) intensity of interference fringe; b) position of fine particle; c) position vertical to the interference fringe inside the intersection of the two laser beams; 29, 30) laser beams, 31) intersection, 32) interference fringe.

[FIG. 3]



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[FIG. 4]